UNIVERSITY OF CAMBRIDGE

DATA SCIENCE AND AI FOR SUSTAINABILITY

Conference 2022 | 27 April 2022 | Downing College, Cambridge

SUMMARY REPORT

Energy Interdisciplinary Research Centre

Cambridge Centre for Data-Driven Discovery

DATA SCIENCE AND AI FOR SUSTAINABILITY

As we move towards a zero carbon economy to meet climate change targets, it is critical to identify and tackle data and AI challenges associated with the generation, storage and supply of energy. This is increasingly important from a technology, policy and societal perspective. New technologies for energy networks, smart grids, future cities and future energy trading will require new ways of joined-up thinking about complex datasets, better policy frameworks and government regulation.

This conference brought together academics, industrialists and policymakers to share their research, identify new opportunities and discuss the collaborative work required to harness AI and data science to decarbonise the energy sector.

Image credit: Phil Kiel

PANEL TOPICS

Panel members gave short presentations followed by a chair-facilitated discussion and an audience Q&A session.

I Policy and regulation

What behavioural changes are required and how do we ensure that we create an energy system which is equitable and affordable? What are the policy instruments, frameworks and incentives needed to accelerate decarbonisation and scaling up renewable energy? What are the opportunities for the transition to low carbon generation? How do we prepare the grid and transmission system for future challenges?

Chaired by **Dr Anil Madhavapeddy** (Department of Computer Science and Technology, University of Cambridge)

Panel Members:
- **Julian Critchlow** (Senior Advisor Bain & Company; former DG Energy Transformation & Clean Growth, BEIS)
- **Dr Ronita Bardhan** (Department of Architecture, University of Cambridge)
- **Lucy Yu** (CEO, Octopus Energy's Centre for Net Zero)

II Technologies: energy networks

What are the key challenges, innovations and opportunities for the UK electricity network? How do we adapt and enhance existing networks? How do we create new efficient and effective ones? How do we integrate networks to optimise performance?

Chaired by **Dr Teng Long** (Department of Engineering, University of Cambridge)

Panel Members:
- **Dr Fei Teng** (Department of Electrical and Electronic Engineering, Imperial College)
- **Iulian Nitescu** (Co-Founder and CTO, Graphmasters)
- **Dr Ioannis Lestas** (Department of Engineering, University of Cambridge)

PANEL TOPICS

III Economics: energy market trading
How is data science and AI changing the energy market organisation and design? What are the factors affecting pricing? How do we ensure market stability and minimise cost? How do we embed market resilience and avoid future shocks?

Chaired by **Professor Michael Pollitt** (Judge Business School, University of Cambridge)

Panel Members:
- **Dr Ramit Debnath** (Judge Business School, University of Cambridge)
- **Ciaran Flynn** (Head of Modelling & Analysis, Sembcorp Industries Ltd)
- **Steven Steer** (Lead Data Consultant, Zuhlke)

IV Future cities: buildings
How can we use AI to synchronise buildings energy supply and demand? How can we optimise building management systems? How can data visualisation help run buildings efficiently? How do we adjust building occupancy behaviour by combining technology with social data?

Chaired by **Professor Ajith Parlikad** (Institute for Manufacturing, University of Cambridge)

Panel Members:
- **Ellissa Verseput** (Data Team Lead, Sympower)
- **Dr Jim Scott** (Chief Production Officer, Grid Edge)
- **Dr Jethro Akroyd** (Department of Chemical Engineering and Biotechnology, University of Cambridge)
- **Dr Isabella Gaetani** (Senior Scientist Smart Buildings, Arup)


Image credit: Atanas Paskalev

I. POLICY AND REGULATION

Chaired by Dr Anil Madhavapeddy, Department of Computer Science and Technology, University of Cambridge.

Summary by Arden Berlinger, PhD Student, Department of Plant Sciences.

The Policy and Regulation panel explored how governments might transition to low carbon energy production systems in an effective, equitable, timely, and resilient way. Dr Anil Madhavapeddy opened the session by imparting both the urgency of this energy transition, the precision of the new technologies, and the implementation required to accomplish it. He then introduced each of the three panellists, who gave opening presentations on their diverse experiences working in energy policy.

Julian Critchlow spoke about his work in creating the UK's Net Zero Strategy ahead of COP26, which detailed individual sector strategies and implementation plans. As the recent events in Ukraine have highlighted, there are many challenges in developing such strategies. Critchlow emphasized the interconnectivity within the UK's energy landscape, the need to make choices in securing sustainable energy markets, and the importance of successfully scaling up national low-carbon strategies at a local level. He additionally recognised the need to account for consumer behaviour. Big data and AI can help facilitate an efficient transition from a policy standpoint, and is also more reactive to consumer behavioural insights, both of which are required to accelerate progress towards net-zero.

Dr Ronita Bardhan at Cambridge University's Department of Architecture spoke about her research on the impact of the built environment on energy consumption and health of impoverished people. Her research uses building sensor data to create a picture of the heat conduction and movement in different types of housing. This is then coupled with data on the energy usage within individual apartments, and larger apartment blocks. This thermal and energy usage data are additionally used to understand occupant health. With increasing population growth and urbanisation in many developing countries, this work can lead to more informed and effective green housing projects and policies.

I. POLICY AND REGULATION

Lucy Yu, CEO of Octopus Energy's Centre for Net Zero, focused on using consumer data and modelling to understand individual behaviour, and how that can be incorporated with technology and policy to spur systemic change at all levels. Lucy argued that active changes in policy, industry, and individual action are all required to accomplish net-zero. Her work uses data modelling to investigate how to make low-carbon energy choices more seamless for the consumer. In discussing wider policies, she highlighted the importance of energy storage and flexibility to support the expansion of renewable technologies. One of Octopus's projects looks to automate a household's energy use from the grid to minimise energy pull during high-intensity energy production times.

Following the presentations, Dr Anil Madhavapeddy chaired a Q&A session with the audience. The panellists discussed the challenges in making net-zero achievable in low-income households without government facilitation to mitigate additional costs to consumers, for example, subsidy of heat pumps over traditional gas boilers. Panellists discussed how granular data and modelling, especially those that incorporate human irrationalities and behaviour, makes low-carbon technology more convenient for people, although there are privacy considerations as well. Julian Critchlow suggested that developing countries may achieve a faster transition by 'leap-frogging' directly to a low-carbon technology being introduced for the first time, as opposed to multiple energy systems transitions typical of wealthier countries.

This diverse panel of speakers was able to connect multiple aspects of the energy transition, pointing out the particular ways that smart data and technology can overcome key challenges in achieving net-zero. Collectively, they emphasized that data and modelling works best when it can incorporate the intricacies of human behaviour, make the uptake of energy-efficient technologies low-friction for the consumer, and maintain flexibility and adaptability from national to local and individual scales.

Image credit: Karthik Chandran

Chaired by Dr Teng Long, Department of Engineering, University of Cambridge.

Summary by Dr Shafiq Ahmed, Coordinator, Energy IRC.

Dr Fei Teng, Lecturer in Control and Power at Imperial College London, spoke on data analytics for energy systems, privacy protection, and incentives for data sharing.

Digitalisation of the energy sector will radically change the way we generate, trade and consume energy. By capturing, storing, managing, analysing and making use of big data, digitisation improves energy system efficiency and facilitates decarbonisation with minimum cost. For power systems the primary sources of big data are:

- operational data from Phasor Measurement Units (PMUs). PMUs measure current and voltage by amplitude and phase at selected stations of the transmission system.
- Electricity market data: settlement data, bidding offers etc.
- Supplier and customer data: the biggest source is smart meter data to measure user behaviour and incentivise demand response

Much work has been done over the last five to ten years on machine learning applications in power systems. Firstly, data can be used to quantify demand response and classify customer profiles. It can predict what will happen, and forecast energy consumption and security predictions, for the system operator. Data can be used to make decisions for market bidding, network control and Electric Vehicle (EV) charging management.

Data can be used for non-invasive load monitoring, initially focussed on EVs due to the growing penetration of EVs in households, many of which may not have installed smart meters. To give suppliers and distribution operators EV profiles at the household level, Dr Fei Teng has developed simple algorithms that take advantage of the distinctive features of EV charging. Generally EV charging requires higher energy consumption than other devices and has a relatively stable operation period, so it is easy to disaggregate the EV charging profile from a household's energy usage. Fei Teng has carried out a baseline estimation for the demand response and has developed data-driven methods by creating artificial customer profiles from aggregated datasets.

Fei Teng is working with National Grid to develop grid inertia forecasting. Grid inertia is a form of energy storage which addresses imbalances between supply and demand on electricity grids over very short time periods.

A consumer survey highlighted privacy concerns about sharing data. The majority of consumers (over 80 %) are willing to share smart meter data, usually half-hourly. However this data would be more likely to be shared by consumers if it were anonymised to prevent energy providers from inferring which devices are being used in a house to deduce social demographic information such as employment status, long term illness, household income, house location etc. Differential privacy techniques can be used to add noise to datasets to ensure that individuals cannot be identified. An alternative model, federated learning, uses blockchain-enabled cloud-edge coordination for demand side response.

Another result from the consumer survey was that a large proportion of consumers were happy to share their data if details are provided about how it may benefit the system, as well as benefit themselves. Consumers are aware that their data has value, and many demand compensation for it when given the opportunity. The proportion of consumers willing to share their data increases when consumers are aware of the inferable information embedded within smart meter data. There are differences in attitudes across socio-demographic groups. A hybrid mechanism can bridge the gap using proxy indicators of value. The mechanism for a joint energy and data market is under development.

The next speaker was Iulian Nitescu, CTO, Graphmasters, a collaborative routing company that optimises time and space on roads for the many different types of road users. Selfish routing leads to traffic jams, air pollution, an increase in CO2 emissions, and underused infrastructure. Navigation apps use this type of routing, and typically react to traffic jams by suggesting an alternative route which simply moves the traffic jam to other roads. Collaborative AI-based routing distributes traffic over the entire network in a forward looking manner by allocating an individual slot to each vehicle. This centralised routing reduces congestion by 30 %. In Germany, where most of the app's clients live, this collaborative routing system saves 7716 metric tons of CO_2 annually. 24,000 routes per minute are currently optimised by Graphmasters' NUNAV routing system, based on six million traffic measurements per minute of achieve real-time data optimisation and prediction. This collaborative routing allows cars to reach their destination faster than with selfish routing.

Measurements are obtained from auto sensors, traffic lights, traffic cameras, weather forecasts, radars, historic behaviour, and construction data. The system is used by numerous vehicle manufacturers (e.g. VW, Mercedes), logistics companies (e.g. Hermes, FedEx), city managers, retailers, and event organisers. As most shopping is now conducted online, vehicles, drivers and warehouses are needed as the number of parcels needing to be delivered worldwide in the next five years is predicted to double. This is unsustainable and there is a need to rethink the last mile logistics.

Sociological consequences of using less well-used roads raises other issues, especially rerouting cars through more residential areas. Examples of driving in the US were given where consumers didn't feel comfortable or safe driving through certain neighbourhoods. Delivery drivers who have driven the same route for years are also reluctant to follow the suggested routes.

The final speaker for this topic was Dr Ioannis Lestas at the Department of Engineering, University of Cambridge, who spoke on how to implement distributed control in a low-carbon power grid. Increasing renewable energy usage results in fluctuations of energy generation, removing inertia from the electricity grid and reducing grid stability. This high-inertia grid requirement limits the use of renewables such as wind. Inverter-based control of the grid's power electronics can alleviate this by allowing efficient control of grid power generation at faster timescales that match renewable energy generation fluctuations. More advanced inverter control designs are required to effectively manage demand-side response of the grid than currently-deployed inverter systems. Inverters can also be manufactured to be more energy efficient with the use of higher-performance fast-switching materials.

Maintaining grid inertia requires coordination from different groups from grid operators to power electronics manufacturers. Grid inertia using renewables is demonstrated in micro-grids in Africa, and such systems could be scaled-up. The significant electricity generation, transmission and distribution losses can be reduced by the use of rerouting data, automation of grid control processes, and more efficient power flow. It was agreed that the government can provide subsidies and other incentives to consumers to adopt more energy-efficient electrical appliances, encourage smart metering, and adopt other demand-side solutions.

III. ECONOMICS: ENERGY MARKET TRADING

Chaired by Dr Ramit Debnath, Cambridge Zero, University of Cambridge.

Summary by Dr Shafiq Ahmed, Coordinator, Energy IRC.

Dr Ramit Debnath presented a talk on 'Digitalisation and future of energy policy: Lessons from the global south', on the global south's unique climate and energy challenges. Ramit has worked with the International Energy Agency (IEA) and the renewable energy agency (IRENA) to approach energy challenges in the global south through a policy framework which includes energy providers, utility companies and end-users. A study in India highlighted integration challenges on a national scale, and analysed how lockdown affected this, especially in the building sector. The Indian government is keen to introduce more flexibility in energy generation for the grid, with high renewable targets to reach. Adding the required digitalisation will take longer e.g. there is currently no time-of-use tariff price system to spread peak load such as the Economy 7 tariff available in UK. India requires stronger digitalisation policy support, regulatory frameworks to increase flexibility via grid storage and power plants, advanced digital metering infrastructure to activate the huge demand response potential from India's buildings and transport.

Lockdown shifted the daily energy demand profile as more people worked from home. In 2020, slum rehabilitation housing or social housing data (from non-intrusive load monitoring using AI from smart meter consumption data) showed more air conditioning units used in larger properties than in smaller ones. Contextual knowledge was required to weight variables based on local climate, weather, consumer age, household size, income levels etc. Such variables pose serious challenges collecting reliable digitalisation.

Extended work-from-home or future hybrid working scenarios may demand restructuring of tariff mechanisms across urban India, as results showed that the number of rooms in a household determines energy demand. Due to data restrictions it could not be established whether there was a correlation between room size, income and energy consumption in work-from-home conditions. India's increasingly urbanised population requires rapid smart metering and digitalisation of electricity supply to understand better the factors that shape residential electricity demand in such a complex cultural context.

III. ECONOMICS: ENERGY MARKET TRADING

Ciaran Flynn, Head of Modelling and Analysis at Sembcorp, presented on 'Asset optimisation with data science applications'. Gas storage issues in Europe and the invasion of Ukraine have led to unprecedented volatility. This is coupled with increasing intermittent renewable penetration and dependency, leading to energy scarcity events and more volatile system frequency.

Sembcorp operates across the grid's ancillary services, and owns 1 GW of UK power supply assets, 70 MW of grid-scale batteries, and a CCUS facility at Wilton on Teeside. The Sembcorp portfolio is well-positioned to mitigate the increasing uncertainty and volatility of the grid driven by growth in renewables and the closure of thermal generation. 628 MW of gas-reciprocating engines across 40 locations is used by National Grid to balance a system with contribution from renewables, but the need for further flexibility is growing, and it is becoming harder to predict renewables' contribution to power due to the dependency on weather. With battery and quick-response assets Sembcorp offers multiple avenues towards grid stability, boosting energy trading markets.

Today's energy system landscape comprises adjacent private monopolies and public silos. Unlike the the nationally-run Central Electricity Generating Board (CEGB) which planned the UK's electricity system development before its closure in the 1980s, none of these private or public entities are in a position to engineer coordinated system change, but digitisation can change that by building different parts of the system explicitly with a view to integration, achieving interoperability by design.

III. ECONOMICS: ENERGY MARKET TRADING

The final speaker was Steven Steer, Zuhlke, who presented on 'A grand design to power our future'. He outlined the village well problem: if fifty people live together in a village and there is only one source of water, there are interesting social questions such as who owns the well, who does the water belong to, and who must maintain it? This is a small-scale version of the macroscopic issues with the UK's power.

The government has recently set up an Energy Digitisation Taskforce, which will have a new digital governance approach. Steven Steer advised government on implementation of the taskforce, and proposed a solution on how to reform the sectoral-level governance of the energy sector. The taskforces, set up by BEIS, UKRI and Ofgem, recently produced a strategy for a modern digitalised energy system. Electric grids are essentially one of the world's largest machines, and are very complex. They are so complex that it is only possible to design modern electricity systems with the support of technology, and the use of machines to help to design the optimal grid system. This implies that there is a need to digitise the governance process that guides the energy sector, to enable it to better progress with decarbonisation of energy.

Steven's governance solution is a hybrid between the UK's old nationalised central planning method and that of the highly liberalised energy market of today. The solution includes an open knowledge-base to serve as a digital blueprint of the energy system's current design and ongoing investments. It also includes an 'enterprise architecture' approach to gaining control over the system design, including a system architecture design authority (a 'Digital Delivery Body') to coordinate across organisations' digital engineering investments. Agile working methods are also included to create rapid feedback loops with a panel of stakeholders to serve as proxies for competition. Steven's proposes a hub-and-spoke operating model to orchestrate detailed engineering design between organisations in the sector, ultimately advocating for greater prominence of enterprise architecture and practical digital/data engineering to make sustainable and affordable energy services possible.

Ramit Debnath chaired the Q&A session which covered a wide range of topics. Digitalisation of governance processes allows us to look at pricing, tariffs, load-shedding and downstream market design in a different way. However, the energy transition is not likely to be affordable for consumers alone, relying heavily on industry to pay for new technology such as CCUS, and for government incentives to transition to new, more energy-efficient technologies.

Forecasting power prices is key to the optimisation process. Optimisation models are used to predict market prices under normal market conditions. However, during market scarcity these dynamics change, and such models underperform. Machine learning may help to identify when the behaviour of the market changes in order to better predict market behaviour and stabilise prices.

Frequency response is used to restore the system frequency to safe levels. Increasing renewables usage has resulted in a need for more battery assets and more scope to switch markets to maintain system flexibility and stability. Predicting the need for frequency response can be challenging, and requires close dialogue with the market operator, especially given that renewables' supply is affected by too many weather and climate variables to develop simple models, hence the need for robust machine learning to aid the optimisation decision.

Chaired by Prof Ajith Parlikad, Professor of Asset Management at Cambridge University Engineering Department.

Summary by Dr Shafiq Ahmed, Coordinator, Energy IRC.

The first speaker in this session was Ellissa Verseput, Data Team Lead at Sympower, speaking about empowering renewable electricity grids using AI. Founded in 2015, Sympower connects flexible devices to a software platform in order to control energy usage as the shift to renewables and electrification lead to grid volatility and congestion. Processes are pooled together from different customers and are offered as a single pool to an electricity grid operator using two key solutions: distributed flexibility at commercial sites, and AI. Renewable energy generation leads to increasing intra-day frequency imbalances between supply and demand of electricity. Transmission system operators can balance the grid by using primary, secondary and tertiary reserves that mitigate energy drops. Flexible energy generators can offer their availability to fill the demand for the appropriate MW amount required, the time and duration required, and the price per MWh. Traditional sources of flexibility have been conventional grid-scale generators such as transmission system operators, as well as balancing-responsible entities to enable power plants to adjust their production.

However there is now untapped flexibility on the demand and the supply side, such as the distributed flexibility that can be harnessed by large scale industrial and commercial buildings, factories, data centres, greenhouses etc. These buildings all consume large amounts of energy and may be used to provide storage and enhanced consumption to balance markets. The EU is promoting the use of aggregated distributed flexibility on the energy market, which will reduce the need for conventional fossil fuel generators.

Sympower's platform combines hardware (local and cloud-based data storage networks, as well as metering hardware) and software to generate data and AI applications. There are AI challenges for bidding e.g. knowing how much flexible power is available at any time, anticipating the price levels, and market bidding strategies to apply to each MW of flexible power at which price at any time. The daily forecasting of controllable power in production is a five-step automated process (1) historic controllable power data from external sources is inputted, (2) data is prepared by cleaning it and featurising before inputting into the AI model, (3) resources receive their own machine learning model, (4) individual forecasts are combined and quantification rules applied, and (5) human intelligence is required to review the forecasts before sending it to markets.

The next speaker was Dr Jim Scott from GridEdge, who spoke about reducing the carbon impact of the buildings by enabling communication between the energy system and the built environment. The system collects data and predicts the usage of heating, lighting, and ventilation systems with pre-set carbon targets to choose from, for example a 5 % carbon reduction will not be noticeable by building users, but will result in the system suggesting when to turn off heating during certain times determined by when electricity is cheapest. Being able to switch between cost savings and carbon savings is useful depending on the priorities of the personnel in charge. This demand-side response can be used by EV-to-grid charging/discharging cycles, saving energy until needed.

Jim Scott has designed different user persona paradigms for GridEdge. 'Clever Carly' is an example of a company's sustainability director or similar role. She is responsible for the planning and delivery of the net-zero strategy across a company and she reports to, or sits on, the board. Clever Carly genuinely cares about saving the world and doing her bit to make positive changes. She is in full support of the company's sustainability targets. A good day would be making positive impact stories, seeing real progress, being seen as a leader and getting buy-in for net-zero. Someone like this is a typical purchaser of the GridEdge software. Carly is likely to have limited knowledge of technology or energy, have competing pressures, and may face competition to have their voice heard in comparison to those driving non-sustainability agendas.

Another user persona is 'Reliable Raj' who is in a mid-level manager role and works for Carly. He would be responsible for measurement of progress and delivery of projects within the company's net-zero strategy. He would be multi-skilled very busy site-managing a large real-estate portfolio. He cares about the future and keeps informed about the latest trends. A good day would be connecting action with vision, focussing on data, looking for big energy and cost savings. However he is time-poor and data-rich, and manages multiple stakeholders.

The third persona is 'BMS Bill' who is responsible for the building management system, keeping the building open and the occupants comfortable. This involves mechanical, electrical and IT fixing. It is a very varied, engineering job. Bill wants to do a good job and help people. He is reliable but isn't a fan of change or fuss, and likes to be informed and involved in decisions. A good day is to go home early, seeing new innovations, and having his opinion heard, but he is invisible to the building users.

GridEdge has used these personas to improve their net-zero journey with complex data, which needs rapid interpretation to identify and solve energy problems quickly. A flexible system would empower each of these company personas to have more ownership of their energy goals and therefore implement the changes required for the company to reduce energy usage, and therefore carbon emissions.

The third speaker was Dr Jethro Akroyd from the Department of Chemical Engineering and Biotechnology, University of Cambridge. His presentation was on 'Digital twins and semantic technology – The World Avatar project a universal digital twin'. The World Avatar project is part of an ongoing collaboration between the University of Cambridge, the Cambridge Centre for Advanced Research and Education in Singapore (CARES), established in 2013 as a platform for collaboration between Cambridge and Singapore, and CMCL Innovations, a university spin out established in 2008.

Digitalisation will facilitate sustainability in a future energy landscape with many interconnections. For example, recent reports about the role of hydrogen in the future energy landscape span the electrical power system, the gas grid, the potential of biomass, solar and wind energy, transport systems, and the heating of commercial and domestic buildings. The Internet of Things contains numerous inter-connected devices/sensors which may be used to link data between these systems. This provides a data-rich environment and an opportunity to generate cyber-physical systems with high levels of integration between physical and computational elements and the Internet of Services (IoS). Exploiting these opportunities to achieve sustainability presents challenges such as ambiguity of data causing high friction in the exchange, integration and use of models and data between interconnected systems. The World Avatar project explores a potential solution based on knowledge graphs.

The World Avatar (TWA) aims to provide a principled way to represent any aspect of the real world in a digital world, using ontologies to provide semantic models of domains of interest. Data, software and models describing the domains are represented using these ontologies, resulting in a knowledge graph. This provides a uniform framework that enables the representation of information and the sharing of knowledge between any domains of interest. Computational agents (computer programs that provide applications and services) also form part of TWA and are themselves described in, and operate on, the knowledge graph. Computational agents perform tasks such as data input and output, estimating quantities of interest, simulating the behaviour of systems or updating old system behaviours due to changes elsewhere in the knowledge graph. The resulting system can be used in three ways: (i) to answer questions about the state of the world, (ii) to control systems and (iii) to explore "what if" scenarios. Dr Akroyd presented examples of these three uses in an energy and resilience context.

IV. FUTURE CITIES: BUILDINGS

TWA may be used describe towns and cities, and their infrastructure networks including the electrical power and gas transmission systems connecting them. TWA can also be used to describe land use and can resolve geospatial queries, for example the energy available from locally grown crops. It can describe building data, including the geometry and features of the building, individual apartments and rooms within buildings. Examples were presented, including the representation of around 23,000 buildings in Berlin, demonstrated in the Climate Resilience Demonstrator (CReDo) project as part of the National Digital Twin programme, where the ability to cascade updates through the knowledge graph was exploited to investigate the system-wide resilience of the combined energy, telecoms and water networks to climate-related flood scenarios in the Southeast of England.

The ability of TWA to control systems in the real world was explored by connecting it to the CARES laboratory building management system in Singapore to calculate the cooling water circulation rate required to cool the building. A second case study was presented where TWA methods were applied to optimise the operation of a district heating network in a town in Germany. Cost savings of up to 25 % and energy savings of up to 50 % were identified.

A "what if" case study was presented that combined geospatial data about energy usage, climate patterns and fuel poverty to ask what would happen if air source heat pumps were used instead of gas for domestic heating. It was predicted that emissions would reduce by around 1000 kgCO2eq/year/household. But what would this cost and who would be affected? It was shown that fuel costs would, in general, increase and that some of the largest increases would occur in regions with the highest rates of fuel poverty (at 2019 prices). This was presented as an example of how data could be used to support local policy-making to balance the social and technical challenges of decarbonisation.

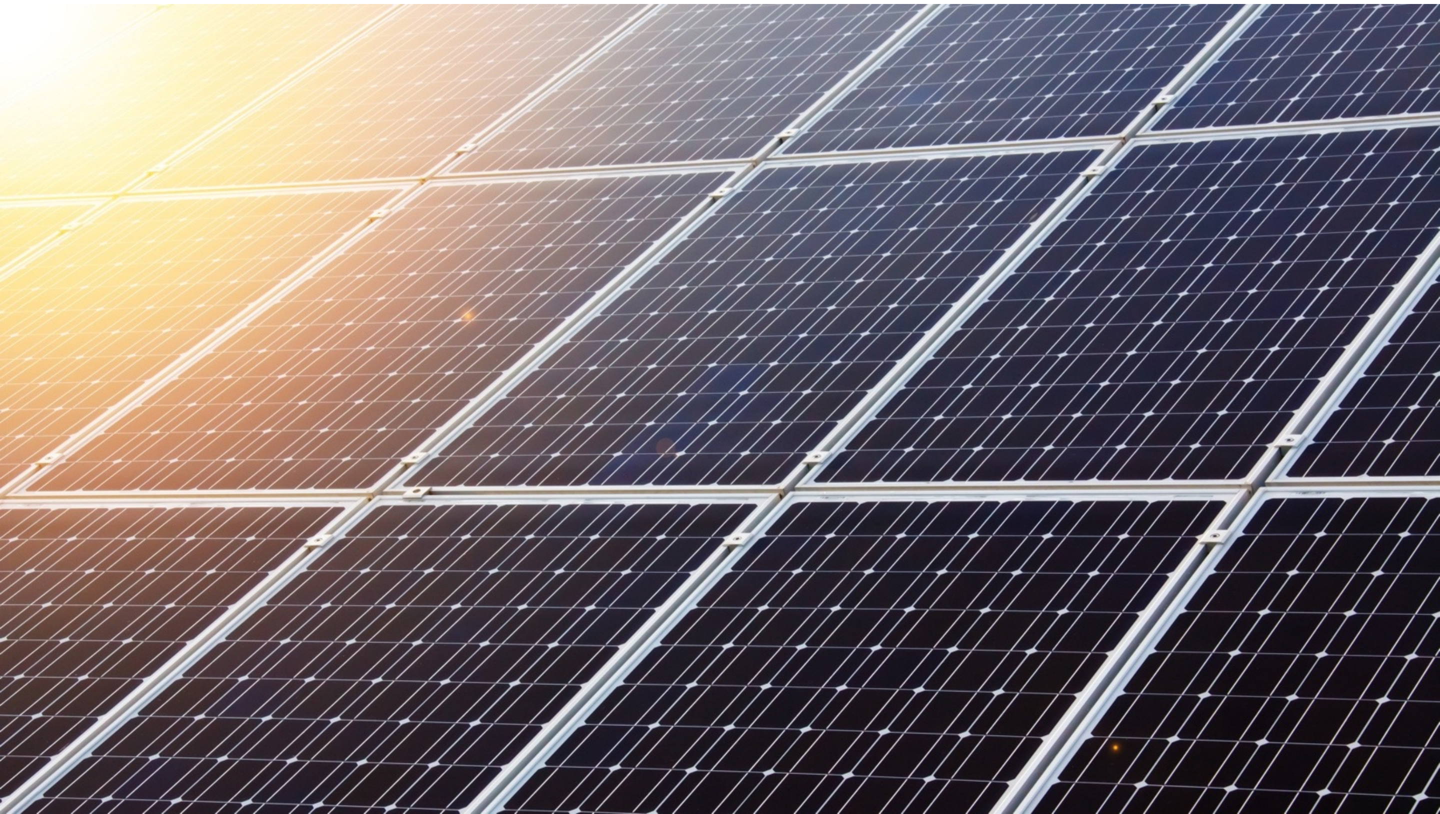
The final speaker was Dr Isabella Gaetani from Arup who discussed the challenges of today's ubiquitous application of AI in the built environment. She reminded us that we spend over 90 % of our time in buildings, hence our buildings must be people-centred while having the lowest possible impact on the planet. The construction sector traditionally lags behind in AI adoption, however Arup offers AI-enabled services such as uncovering energy-saving opportunities via big data analytics to understand hidden patterns, machine learning-enabled capabilities, prediction of maintenance needs, and AI-assisted building operation. Yet, an integrated approach to AI in the built environment is full of challenges. The art of collecting, cleaning, and preparing data for analysis starts from smart building design to enable building data to be generated. The vendors, contractors, sensor systems, and validation of compatible data flows must be optimised. Isabella showed the impact of Covid-19 on the energy use of Arup offices and the actions taken based on this knowledge.

Dr Ajith Parlikad chaired the Q&A session to address the question: can data and machine learning monitor embodied carbon in buildings as well as carbon emissions? This is currently only possible in new buildings e.g. concrete with lower embedded carbon has recently become available although the market is still in its early stages. Arup is looking at life cycle analysis of all parts of its buildings. Typically windows at the end of their life are broken into pieces and recycled. Arup now uses robots to cut out single panes of glass for re-use, and are exploring extending the lifetimes of other assets in the same way.

The built environment of the future will need a workforce with broad skills sets such as design engineers, virtual construction workers and asset managers. Those with new skills who can speak across disciplines, and those who have upskilled to adapt their existing roles and responsibilities in the sector will manage the buildings of the future.

Dr Colm-Cille Caulfield, Department for Applied Mathematics and Theoretical Physics, University of Cambridge, closed the conference with some final remarks and thanked C2D3 and Energy IRCs for organising the event.

The conference was kindly sponsored by the Isaac Newton Trust and NERC.



CHAIRPERSONS AND PANELLISTS

Professor Colm-cille Caulfield is Head of the Department of Applied Mathematics and Theoretical Physics (DAMTP), University of Cambridge. His research focuses on (trying to) understand turbulence and mixing in environmentally- and industrially-relevant flows, including heat transport in the world's oceans, the dynamics of volcanic plumes, and the design of building interiors to minimise energy use while maintaining comfort and safety. More recently, he has become interested in addressing research problems relevant to the modelling of our rapidly changing climate using a twin-pronged approach of physics-informed and data-driven methods in combination.

Dr Anil Madhavapeddy is an Associate Professor at the Department of Computer Science and Technology in the University of Cambridge. He has worked in industry (NetApp, Citrix, Intel), academia (Cambridge, Imperial, UCLA) and startups (XenSource, Unikernel Systems, Docker) over the past two decades. At Cambridge, he directs the OCaml Labs research group which delves into the intersection of functional programming and systems. He is a long-time maintainer on open-source projects such as OpenBSD, OCaml, Xen, and Docker, and a seasoned entrepreneur who advises companies on technology strategy (currently Zededa, Tezos Foundation, Tarides, and others).

Julian Critchlow was Director General of Energy Transformation and Clean Growth at the Department for Business, Energy and Industrial Strategy (BEIS) from May 2018 to March 2021. During his tenure, the UK legislated for Net Zero by 2050, set a globally-leading sixth Carbon Budget, published a comprehensive Net Zero Strategy with associated sectoral plans for all parts of the economy, and took on the Presidency of COP26 in Glasgow. Prior to joining the UK civil service, Julian was a Director at Bain & Company. He led Bain's Global Utilities & Alternative Energy Practice, working with senior executives in leading utilities around the world on their key strategic, operational and organisational issues.

Dr Ronita Bardhan is Assistant Professor of Sustainability in Built Environment at the Department of Architecture, University of Cambridge, leading the Sustainable Design Group and conducting research on how a sustainable built environment informs health and energy decisions in a warming climate. Ronita has instrumented data-driven methods that couple architectural engineering, AI and machine learning with social sciences, to provide contextualised built environment design solutions in resource-constrained societies.

Lucy Yu is CEO at Octopus Energy's Centre for Net Zero, an impact-driven research unit focused on delivering a fast, fair and affordable energy transition. Lucy has nearly twenty years of experience in technology, policy and regulation. She has led teams in the UK government's Cabinet Office, Department for Transport, and Centre for Connected and Autonomous Vehicles (CCAV), and at the UN's International Telecommunication Union. Her work has focused on future mobility and cities; sustainability and renewable energy; and AI, data, and digital technologies. She has written extensively on these topics for the tech press and peer-reviewed journals. Outside government she has run operations, public policy, research and strategy functions for some of Europe's brightest startups including SwiftKey (artificial intelligence); Voi Technology (micromobility); Cucumber (software development); and Five (autonomous vehicles).

CHAIRPERSONS AND PANELLISTS

Dr Teng Long is a Lecturer at the University of Cambridge, and leads the Applied Power Electronics Laboratory in the Department of Engineering. Teng's research covers power electronic devices, power converters, and drive and power systems, mainly for transport electrification and renewable energy applications. Teng had been awarded more than £2.4 million in research funding, around half from industrial sponsors including collaborations with SAIC Motor, Dynex Semiconductor, STMicroelectronics, Siemens, CBMM, CRRC, Wuxi SES. Prior to joining Cambridge, Teng worked for General Electric (GE).

Dr Fei Teng is the education director of Energy Futures Lab and a lecturer in the Department of Electrical and Electronic Engineering at Imperial College London. He holds visiting positions at MINES ParisTech, France and PloyU, Hong Kong.
His research focuses on the efficient, secure, and resilient operation of future cyber-physical energy systems. He has been involved in over £3 million research grants in the last five years from EPSRC, ESRC, Innovate UK, Royal Society, EDF Energy, and National Grid ESO.

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CHAIRPERSONS AND PANELLISTS

Professor Michael Pollitt Assistant Director of Cambridge's Energy Policy Research Group and is Professor of Business Economics at Cambridge's Judge Business School. He is a Fellow of and Director of Studies in Economics and Management at Sidney Sussex College, and is also a Research Associate of the Centre for Business Research. Michael's research interests include regulation, privatisation and liberalization in the network industries; cross national efficiency comparisons in the electricity industry; business ethics, social capital and corporate governance.

Dr Ramit Debnath is a Sustainability Fellow at Churchill College, University of Cambridge and visiting faculty associate in Computational Social Science at Caltech. Ramit is a research associate at Cambridge's Energy Policy Research Group and the Centre for Natural Materials Innovation. Ramit works at the intersection of data science and public policy, focussing on developing novel multi-method approaches to natural language processing, machine learning, AI and qualitative analysis to support a people-centric and just transition. Ramit also explores how the public, industry and policymakers make decisions for energy and climate justice and developing solutions to counter misinformation and distributive injustices. Ramit has previously worked with the International Energy Agency in their Energy Efficiency and Digitalisation team.

Ciaran Flynn Head of Modelling and Analysis at Sembcorp. Ciaran is an experienced structurer and quantitative analyst/manager with a history of working in the energy industry covering renewable, generation and retail business sectors. He is skilled in market risk, quantitative finance, energy markets, product management, financial structuring, stakeholder management and communication.

Steven Steer is Lead Data Consultant for Zuhlke Engineering and previously held the role of Head of Data at Ofgem. Steven was previously a member of the University of Cambridge's Energy Policy Research Group. Steven's contribution to the digitalisation of energy services includes setting up and advising the UK's Energy Data Taskforce (EDTF), co-creating the government's Modernising Energy Data (MED) programme, and he is creating and undertaking the legal arrangements for Ofgem's regulatory standards on data and digitalisation in the energy sector.

CHAIRPERSONS AND PANELLISTS

Professor Ajith Parlikad is Head of the Asset Management Research Group at the University of Cambridge. Ajith leads research activities on engineering asset management and maintenance. His particular focus is examining how asset information can be used to improve asset performance through effective decision-making. He actively engages with industry through research and consulting projects. He is currently the Scientific Secretary of the IFAC TC5.1 Working Group on "Advanced Maintenance Engineering, Services and Technology" and sits on the steering committee of the UK Digital Twin Hub. Ajith's current research focusses on the development and exploitation of digital twins of complex asset systems bringing together data from disparate sources to improve asset management.

Ellissa Verseput is the Data Team Lead at Sympower, a company that stabilises the electricity grid by unlocking the inherent flexibility of its customers' electricity usage. In the past, Ellissa worked on energy-saving services for domestic smart thermostat users. In her current role she is responsible for the team that provides AI-based forecasting and analytics, required to optimise and automate Sympower's flexibility services.

Dr Jim Scott is co-founder and Chief Product Officer of Grid Edge, a company that provides data science and machine learning software to consumers to help them deliver their decarbonisation strategies, from efficiency to flexibility. Jim builds products that empower energy consumers to foresee and act on the opportunities available to them through the energy transition. Jim has worked in cleantech and renewable energy technologies for his whole career working across a variety of generation-side sectors and on energy efficiency projects for commercial and industrial consumers and for municipal districts.

Dr Jethro Akroyd holds positions at CMCL Innovations, a multi-award-winning SME, and as a Senior Research Associate in the Computational Modelling Group at the Department of Chemical Engineering and Biotechnology (CEB), University of Cambridge. Jethro has worked extensively with the Cambridge Centre for Advanced Research and Education in Singapore (CARES) to develop solutions to enable the cross-domain interoperability of data and models, with a focus on applications relating to sustainability and the energy transition.

Dr Isabella Gaetani is a Senior Scientist working within the Arup Smart Buildings Team. Isabella's work focuses on unlocking the power of data to increase our understanding of human-building interaction to achieve higher energy and comfort performance of buildings. A building simulation specialist, Isabella is also active in the fields of digital twinning and smart enablement. During her PhD, Isabella developed a method to improve the modelling of occupant-related uncertainties in building performance simulations, thus leading to improvements in the energy performance and indoor environment of buildings.

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